

Conformal, Amine-Functionalized Thin Films by Initiated Chemical Vapor Deposition (iCVD) for Hydrolytically Stable Microfluidic Devices

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Received October 13, 2009. Revised Manuscript Received January 4, 2010

Poly(4-aminostyrene) (PAS) thin films were synthesized via initiated chemical vapor deposition (iCVD) with *tert*-butyl peroxide as the initiator, representing the first time that a library of iCVD functional groups has been extended to amine moieties. The retention of the pendent amine chemical functionality was confirmed by Fourier transform infrared spectroscopy (FTIR) and X-ray photoelectron spectroscopy (XPS). Scanning electron microscope (SEM) reveals that the iCVD PAS coatings are conformal over nonplanar structures. Fluorescence microscopy and photoluminescence of quantum dot functionalized surfaces confirm that the reactive amine functional group density at the surface of iCVD PAS is ~ 1 order of magnitude greater than for films grown by plasma-enhanced chemical vapor deposition (PECVD). The higher amine density of the iCVD films enables the formation of a robust nanoadhesive with complementary epoxy functional groups. Prototype microfluidic structures were fabricated using the low-temperature (50 °C) and zero-outgassing reaction between the amine groups in iCVD PAS and the epoxy groups in iCVD poly(glycidyl methacrylate) (PGMA). Bonded devices able to withstand > 150 psi were achieved by combining polydimethylsiloxane (PDMS) and a variety of other materials including Si wafers, polycarbonate (PC), glass, polyethylene terephthalate (PET), polyethylene (PE), polyacrylate (PA), and cyclic olefin copolymer (COC). Additionally, the all-iCVD nanoadhesive bonding process displays high resistance against hydrolytic degradation (> 2 weeks). Within the channels of the bonded devices, the epoxy and amine groups remain available for subsequent functionalization.

Introduction

Modification with specific organic groups is critical for controlling the functionality of the surface. The organic functional groups can be utilized to tune surface energy; to enable subsequent chemical attachment of desirable molecules, such as fluorescent dyes, antibodies, or cell growth factors; or to covalently bind micro- or nanoparticles to the surface. Common functional groups include amine ($-\text{NH}_2$), carboxylic acid ($-\text{COOH}$), epoxy ($-\text{C}_2\text{H}_3\text{O}$), hydroxyl ($-\text{OH}$), and aldehyde ($-\text{COH}$).¹ Amine-functionalized surfaces are of particular interest as they provide a versatile platform for detection of biomolecules.² Primary amine groups can react with a variety of functional groups including epoxy, aldehyde, carbonyl, carboxylic acid, sulfonyl chloride, and nitrous acid.³ Surfaces with amine groups can be functionalized either by direct attachment of specific binding groups, or through the use of various chemical linkers.¹

Some existing methods to obtain amine-functionalized surfaces include direct adsorption of polylysine,⁴ amine silanization,^{5–7} incorporation of polyamidoamine dendrimers,⁸ and amine self-assembly.⁹ Each of these approaches has one or more drawbacks such as poor stability, substrate specificity, multistep processing, and the requirement for solution phase chemistry. Gas-phase treatment, including atomic layer deposition (ALD)¹⁰ or chemical vapor deposition (CVD),^{11,12} is desired for surface modification of substrates that would swell or degrade in solvent. It is also desired for polymers that are insoluble or that dissolve only in harsh, toxic, or expensive solvents. A plasma-enhanced chemical vapor deposition (PECVD) method

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using plasma-polymerized ethylenediamine (PPEDA) was employed to coat glass slides with amine functional groups.¹³ However, this approach generally suffers from the drawback of poor amine functionality retention and lack of chemical selectivity because of the plasma environment.

The iCVD method has shown great promise as a surface modification technique, and it has successfully been used to create many distinct homopolymers, random copolymers, and alternating copolymers using free radical polymerization.^{12,14} It is chemically comparable to solution-phase polymerization but is environmentally friendly, able to achieve good conformality, and able to maintain the chemical functionality in the monomers. Amine-functionalized iCVD surfaces have not yet been reported. Selection of a monomer is challenging because many candidates have low vapor pressures as a result of hydrogen bonding between amine groups. However, some commonly used monomers such as ethylamine and allylamine (AAM) are too volatile (vapor pressure, $P_{\text{sat}} > 240$ Torr at 25 °C) for the iCVD system and cannot be operated within the optimum process window of $\sim 0.4 < (P/P_{\text{sat}}) < \sim 0.7$, where P is the partial pressure of the monomer in the reactor.¹⁵

In this work, 4-aminostyrene (4-AS) is chosen as a precursor (vapor pressure = 0.0415 Torr at 25 °C), which is compatible with the iCVD process. The conformality, surface concentration of amine functional groups, and nanoadhesive capabilities of the iCVD PAS will be compared to amine-containing films grown from PECVD utilizing the monomer AAM. The latter was chosen for comparison as it was previously demonstrated to be useful in a novel nanoadhesive bonding scheme¹⁶ which at the same time leaves epoxy and amine functional groups inside the microchannels, providing a direct route for further functionalization.

Bonding of the microfluidic devices is achieved via a ring-opening curing reaction between amine groups from PAS and epoxy groups from poly(glycidyl methacrylate) (PGMA), both of which were synthesized via iCVD. It has several advantages over conventional binding techniques. Direct bonding and anodic bonding can achieve high bonding strength, but those techniques require high bonding temperatures and have the potential to damage surface functionality. However, with a process temperature of 50 °C, this problem can be avoided. In addition, well-controlled thin conformal coatings can be achieved via iCVD, which prevents the blockage of the microfluidic channel. This bonding process involves a relatively fast reaction rate at low temperatures and can be applied to many different types of polymer substrates, making it a general bonding method for fabrication of microfluidic

devices. Furthermore, the deposited samples are stable under dry conditions and can be stored for more than 2 months prior to bonding. This process has advantages over the conventional oxygen plasma sealing technique where immediate bonding is needed. More importantly, all four walls of the microchannel will have reactive coatings.

Conventional sealing requires any functionalization process to be completed before the microchip can be sealed. Chen *et al.* applied chemical vapor deposition to previously assembled microfluidic devices and successfully deposited reactive coatings within confined microgeometries.¹⁷ Despite this result, the process likely cannot be applied to complex microgeometries, and they give no evidence that the coating inside the microchannel is conformal, which may introduce difficulties such as functional group density variations and channel clogging. Recently they developed a solventless adhesive bonding (SAB) technique using reactive coatings, which can be applied to substrate materials other than PDMS.¹⁸ Bonding is achieved through the reaction of the aldehyde and amine functional groups present in poly(4-formyl-p-xylylene-co-p-xylylene) and poly(4-aminomethyl-p-xylylene-co-p-xylylene). However the formation of the covalent tethers between the complementary surfaces produces a gaseous by-product, which could result in surface defects and lower bond strength. In addition, the curing temperature for the reaction is 140 °C, which is higher than the glass transition temperature of some polymeric substrates.

A novel method has recently been developed by Im *et al.*¹⁶ The bonding was achieved by putting a prepatterned surface with iCVD-deposited PGMA into contact with a flat PDMS substrate with plasma-polymerized poly(allylamine) (PAAm), followed by curing at 70 °C. The sealed device is able to withstand pressures as high as 50 psi under dry conditions. Compared with Im's work, this process applied the iCVD method to both the substrate and the cover plate, which enables good conformality inside the microchannels. Avoiding exposure of the substrates to plasma will prevent plasma damage of the substrate and also create a higher density of amine functional groups, resulting in stronger bonding. In this work, bond strength in the aqueous environment was also investigated.

Experimental Section

Film Preparation. All iCVD films were deposited in a custom-built vacuum reactor (Sharon Vacuum), as previously described.^{15,19} Thermal excitation was provided by heating a nichrome filament (80% Ni/20% Cr) mounted in a parallel array, and the temperature was measured by a thermocouple attached to one of the filaments. The filament holder straddled the deposition stage, which was maintained at a set point temperature using water cooling. The vertical distance between the filament and the stage was 2 cm.

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All the chemicals were used as purchased without further purification. *tert*-Butyl peroxide (Aldrich, 97%) initiator, at room temperature, was fed into the reactor through a mass flow controller (model 1179A, MKS) at 1 sccm. 4-Aminostyrene (4-AS) (Aldrich, 97%) monomer, heated to $85 \pm 3^\circ\text{C}$ in a glass jar, was delivered into the reactor at 0.8 sccm via a different port. Films were deposited at a filament temperature of 260°C and a stage temperature of 50°C . iCVD deposition conditions utilizing the monomer glycidyl methacrylate (Aldrich, 97%) were adopted from previous work reported by Mao.²⁰ Total pressure in the vacuum chamber was maintained at 0.35 Torr and 0.22 Torr for 4-AS and GMA depositions, respectively.

For each polymer, nine different kinds of substrates, each $\sim 8\text{ cm}^2$ in area, were simultaneously coated via iCVD: (1) Si wafer, (2) polydimethylsiloxane (PDMS), (3) polycarbonate (PC), (4) glass, (5) polyethylene terephthalate (PET), (7) polyethylene (PE), (8) polyacrylate (PA), and (9) cyclic olefin copolymer (COC). All of these substrates were cleaned for 0.5–1 min with oxygen plasma (13.56 MHz, 100 W/cm², 100 mTorr). Film growth on the Si substrate was monitored in situ through laser interferometry and controlled to a thickness of 200–250 nm. A more accurate film thickness on the Si wafer substrates was measured postdeposition by a J. A. Woollam M-2000 spectroscopic ellipsometer at a 70° incidence angle using 190 wavelengths from 315 to 718 nm.

Using the plasma polymerization conditions and reactor configuration were reported by Im et al.¹⁶ Si, PDMS, PC, and glass substrates were coated with PECVD polyallylamine (PAAm) to a thickness of $\sim 50\text{ nm}$.

Film Characterization. Fourier transform infrared (FTIR) measurements were performed on a Nicolet Nexus 870 ESP spectrometer in a normal transmission mode. A deuterated triglycine sulfate (DTGS) KBr detector over the range of $400\text{--}4000\text{ cm}^{-1}$ was utilized with a 4 cm^{-1} resolution. Films were measured immediately after deposition, and measurements were averaged over 64 scans to improve the signal-to-noise ratio. All spectra were baseline-corrected by subtracting a background spectrum of the Si wafer substrate. FTIR was also performed on a commercial sample of PAS (Polysciences) that was incorporated into a KBr pellet.

An X-ray photoelectron spectroscopy (XPS) survey spectrum was obtained on a Kratos Axis Ultra spectrometer with a monochromatized Al K α source. Relative sensitivity factors were calibrated by measuring poly(N-isopropylacrylamide) polymer (Aldrich) spun-cast onto a Si wafer. Deposition samples and the standard were stored under vacuum overnight prior to analysis.

Both iCVD and plasma-polymerized polymers were deposited on silicon substrates patterned with trenches supplied by Analog Devices. These trenches were $7\text{ }\mu\text{m}$ deep and $0.8\text{ }\mu\text{m}$, $1.3\text{ }\mu\text{m}$, $2.1\text{ }\mu\text{m}$, and $5\text{ }\mu\text{m}$ wide, respectively. Deposited trench wafers were sputter-coated with 6 nm of gold (Denton Desk II), and SEM images were obtained by a JEOL JSM-6060 with acceleration voltage of 5 kV.

Fluorescence microscope images were obtained at a $100\times$ magnification using a Zeiss Axiovert 200 inverted microscope with FITC illumination.

Attachment of CdSe/ZnS Quantum Dots. One milligram of commercially available CdSe/ZnS core/shell quantum dots with carboxylic acid surface groups (NN-laboratories, emission = 632 nm) was dispersed in water (20 mL). The solution was ultrasonicated for 30 min to ensure uniform dispersion

(VWR, Model 75D). A small amount of *N,N'*-dicyclohexylcarbodiimide ($< 1\text{ mg}$) was added into the solution afterward. To attach quantum dots, two glass substrates with iCVD-deposited PAS and plasma-polymerized PAAm films were submerged in the dispersion. The jar was placed on a hot plate maintained at 60°C for 2 h. To remove any unreacted, loosely attached quantum dots, the samples were rinsed with deionized water for three times. After being dried and put under vacuum overnight, the samples were analyzed using photoluminescence (PL).

In PL measurements, samples were excited with a coherent Ti-Sapphire laser with a wavelength of 390 nm, a pulse width of 160 fs, and a repetition rate of 250 kHz. A PI Acton SpectraPro SP-2360 Imaging Spectrograph with a PIXIS: 400B Digital CCD camera system was used to collect emitted photons. All measurements were carried out at room temperature.

Bonding of Microfluidic Devices and Bond Strength Test. Linear microfluidic channels of $400\text{ }\mu\text{m}$ wide and $150\text{ }\mu\text{m}$ deep were prepared in PDMS by standard soft lithographic techniques.²¹ After curing at 80°C for 2 h, the PDMS mold with a thickness of 5 mm was peeled off the master. Fluid injection reservoirs were punched before the iCVD deposition.

Scheme 1 shows a detailed bonding fabrication process. Oxygen plasma was applied to the substrates (0.5–1 min), both for cleaning and surface activation to enhance surface energy for better adhesion. PGMA and PAS films were deposited on flat and patterned substrates via iCVD, respectively. After the two substrates were placed face-to-face and ring-opening curing reaction between epoxy and amine groups occurred, microfluidic devices with good sealing could be fabricated. Curing time was intentionally prolonged to 24 h to ensure bond formation. It is important to note here that no additional high-pressure load is needed for the bonding process, and the bonding temperature is much lower than the glass-transition temperature (T_g) of these polymeric substrates.

Burst pressure assessment was performed to measure the bond strength. The channel was filled with water through a $1/16''$ OD capillary PEEK tubing (IDEX Health & Science), and the end of the channel was closed. Epoxy adhesives (Cotronics Corp) were used to glue the tubing and the inlet on the PDMS. A pressure gauge tee connected the testing device to a syringe pump containing freshly deionized water. Water was infused at a flow rate of 10 mL/min to build up the pressure inside the channel and was decreased to 1 mL/min when the pressure gradually increased to $\sim 5\text{ psi}$. The infusion was continued until the channel was observed to burst, with a sudden pressure drop and water leaking from the device. The pressure at which this occurred was reported as its burst pressure.

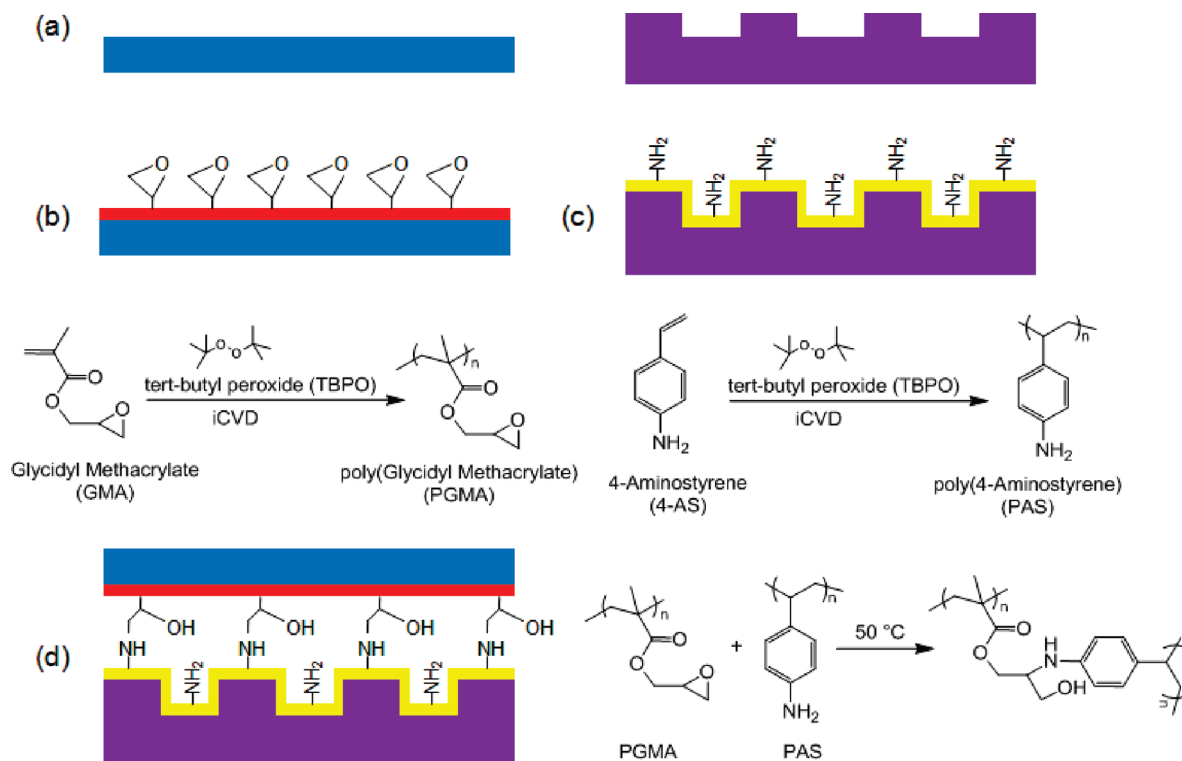
Bonded devices with flat PDMS and prepatterned PC substrates were used for the hydrolytic resistance test.

Results and Discussion

Film Structure Analysis. Figure 1 shows the FTIR spectra of 4-aminostyrene (4-AS) monomer precursor, the iCVD deposited, and the conventionally polymerized PAS films. The 4-AS spectrum (Figure 1a) clearly shows several signatures from vinyl bonds, as denoted by asterisks. Most clearly resolved are the C–H bond out-of-plane deformations arising from $=\text{CH}$ and $=\text{CH}_2$ groups at 990 and 910 cm^{-1} , respectively. The vinyl bonds also contribute to the sharp C=C stretching mode at 1630 cm^{-1} and to the

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Scheme 1. Adhesive Bonding Process^a

^a (a) Substrate cleaning by oxygen plasma for 0.5–1 min, (b) iCVD deposition of glycidyl methacrylate, (c) iCVD deposition of 4-aminostyrene, and (d) adhesive layer curing at 50 °C for 24 h.

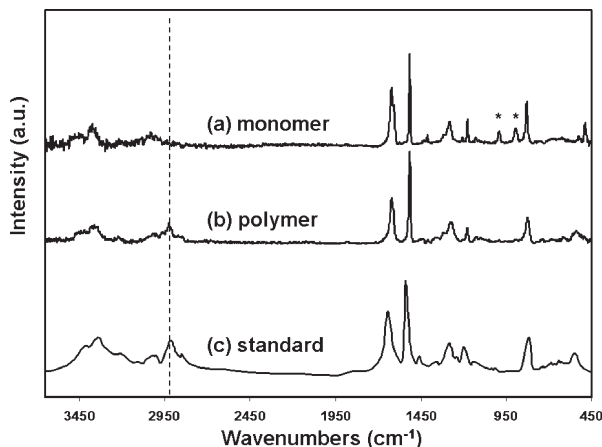


Figure 1. Fourier transform IR (FTIR) spectra of (a) 4-aminostyrene (4-AS) monomer, (b) iCVD deposited poly(4-aminostyrene) (PAS), and (c) PAS standard from Polysciences. Asterisks (*) represent signature vinyl bonds, and the dotted line refers to the sp³ C–H stretching.

sp² C–H stretching modes above ~3000 cm⁻¹. However, the phenyl groups also contribute to these latter features. Film deposition through radical vinyl polymerization is verified by reduction of unsaturated carbon peaks in the spectrum of the iCVD film (Figure 1b) along with the increase in intensity of the sp³ C–H stretching intensity below ~3000 cm⁻¹, indicating formation of polymer backbone containing the saturated carbon groups. As a reference standard, Figure 1c shows the spectrum of commercially obtained conventionally polymerized PAS bulk powder. As seen by comparing parts b and c of Figure 1, peak locations and areas of the iCVD deposited

polymer spectrum match well with the conventionally polymerized PAS standard.

It is important to note that PAS maintains the pendent amine functionality after polymerization, which could be used for further functionalization. The primary amino groups are indicated by signature NH₂ antisymmetric and symmetric stretching at 3420 and 3361 cm⁻¹, respectively.²² This amine is attached to a phenyl group having characteristic C–H stretching modes at 3020 cm⁻¹.

Figure 2 shows the XPS survey scan of iCVD PAS. As expected from the chemical formula for PAS, [C₈NH₉]_n, carbon and nitrogen peaks are observed. In addition, a significant oxygen peak is present. Considering that the XPS sampling depth is approximately 5 nm,²³ the oxygen peak most likely indicates that oxygen incorporation, which is due to either chemical reaction or water adsorption upon exposure to air, has occurred at the film's surface during the 24 to 48 h between the completion of deposition and the time when XPS analysis was performed. Water adsorption is considered to be the main reason because it takes place in milliseconds and is inevitable.

The surface oxygen percentage is 8.8% on a hydrogen-free basis (Table 1). Despite the surface uptake of a species containing oxygen, the ratio of carbon to nitrogen

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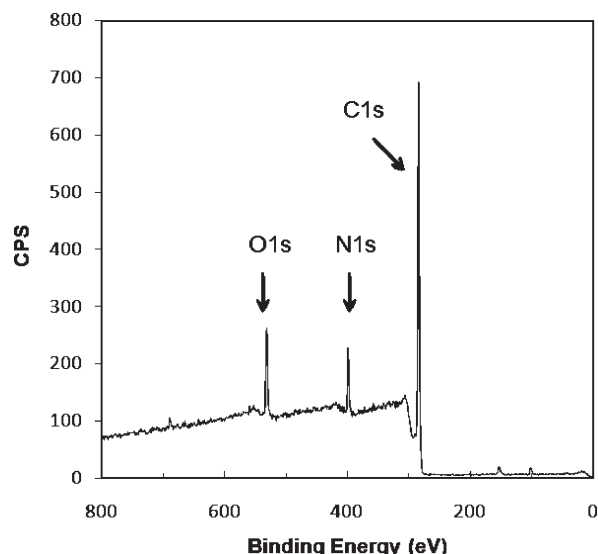


Figure 2. XPS survey scan for detection of the atomic concentration of oxygen, nitrogen, and carbon.

Table 1. Atomic Concentration of Carbon, Nitrogen, and Oxygen

	C	N	O	C/N ratio
binding energy (eV)	284	399	532	
experimental percentage	81.3 ± 3%	9.9 ± 0.4%	8.8 ± 0.3%	8.2:1
theoretical percentage	88.9%	11.1%	0%	8:1

at the surface, 8.2:1, is in reasonable agreement with the ratio based solely on the stoichiometry of PAS, 8:1.

Both FTIR and XPS data support the hypothesis that iCVD produces the same polymeric structure as conventionally polymerized PAS and retains the pendant primary amine functional groups. This is the first time an amine functional iCVD polymer has been synthesized successfully. It not only broadens the iCVD library but also enables many possible applications based on amine functionalization.

Conformal Coverage. For applications including microfluidics, medical devices, and membranes, good step coverage over nonplanar or porous substrates is desired. Step coverage is defined as the ratio of the coating thickness at the bottom to that at the top of the trench. Figure 3 shows the step coverage for iCVD PAS and PECVD PAAM on trenches with different aspect ratios. Clearly the conformality of the iCVD film is superior to that of the PECVD layer. Even for the highest aspect ratio of 8.7, iCVD has step coverage of 90.3%, whereas for PECVD there is virtually no film at the bottom of the trench. The dashed line shows the linear best-fit for the data. This linear relationship ($R^2 > 0.99$) between the logarithm of step coverage and the square of the aspect ratio agrees well with Baxamusa's results for a different iCVD polymer.²⁴

Cross-sectional SEM micrographs (Figure 4) demonstrate the overall profiles for polymer films growing inside trenches with the aspect ratio of 5.5 by iCVD and

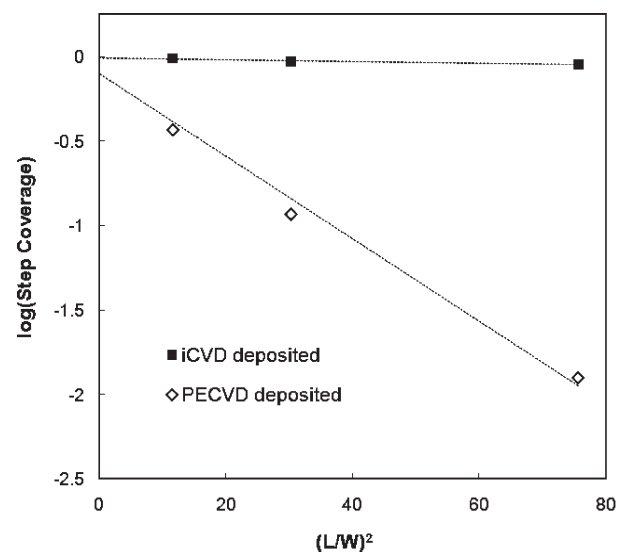


Figure 3. Step coverage as a function of aspect ratio squared. The dashed line ($R^2 > 0.99$) represents the linear best-fit line for the data, and its slope is proportional to the sticking probability of the initiating radical. Here the three different aspect ratios for the trenches are 8.7, 5.5, and 3.4, respectively.

PECVD. The PECVD film (Figure 4b) has little coverage on the side walls or on the bottom of the trench. In contrast, iCVD (Figure 4a) shows very good thickness uniformity over the entire trench feature. Figure 4c indicates the relative thickness variation of these two polymer films with respect to the positions in Figure 4a,b.

Film Derivatization with CdSe/ZnS Quantum Dots. The characterization described above demonstrates that iCVD is able to deposit conformal polymers with retention of amine functionality. To address the question of whether the amine functional groups maintain their reactivity, immobilization studies were carried out using CdSe/ZnS quantum dots with carboxylic acid surface groups. The fluorescent microscope image in Figure 5b shows successful attachment of quantum dots. Three different spots on both PAS- and PAAM-coated samples were analyzed by photoluminescence (PL), and the results are provided in Figure 5a. The intensity on the iCVD PAS-coated substrate is at least 1 order of magnitude higher than on the PECVD PAAM-coated one.

Both the fluorescent microscopy and the PL results from quantum dots immobilized onto the film surfaces indicate that iCVD PAS has a significantly higher density of reactive amine functional groups than does PECVD PAAM. The lower density of amine functionality in PECVD films most likely reflects the partial loss of chemical functionality from the monomers during plasma processing. With lowering of the input plasma power, greater retention of monomer functional groups is possible, but deposition rates also decrease. As a competition process between etching and deposition, PECVD PAAM has a low deposition rate of 2 nm/min. The iCVD film displays a much higher degree of functional retention and also has a higher deposition rate, 10 nm/min, than the PECVD film.

Adhesive Bonding and Bond Strength of Sealed Microfluidic Devices. Adhesive bonding utilizing the iCVD

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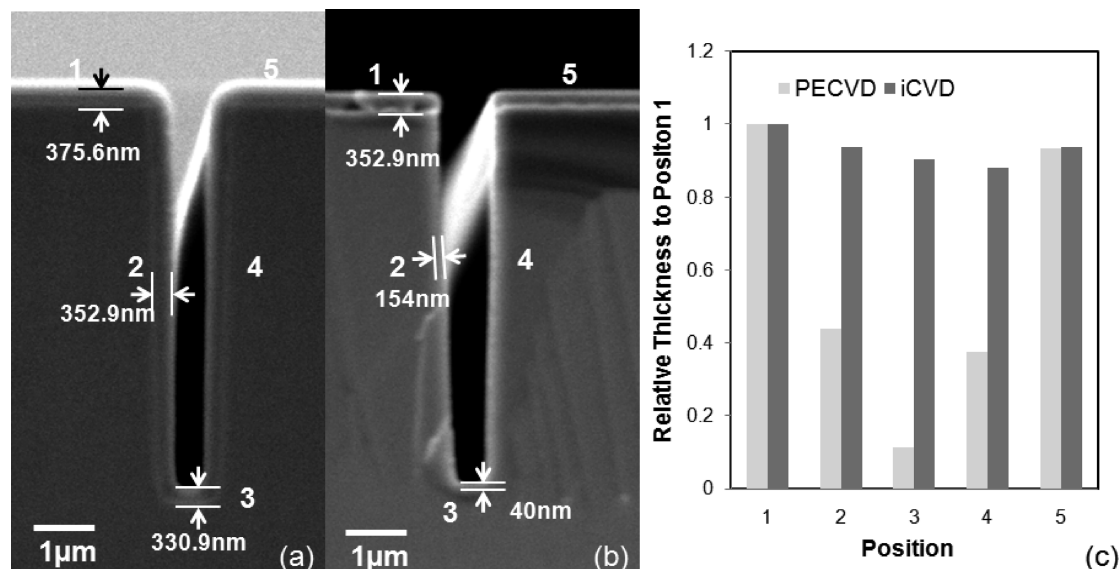


Figure 4. Cross-sectional SEM images films of (a) iCVD PAS, (b) PECVD PAAm, and (c) the relative thickness variation of films with respect to the trench position in (a) and (b).

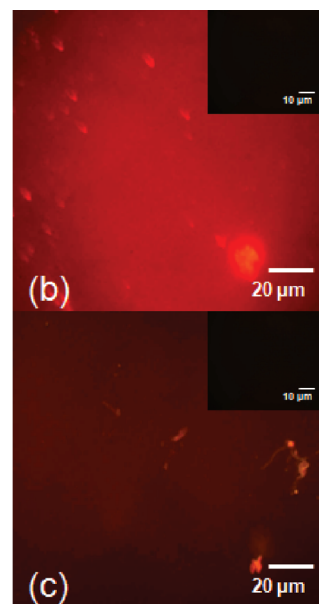
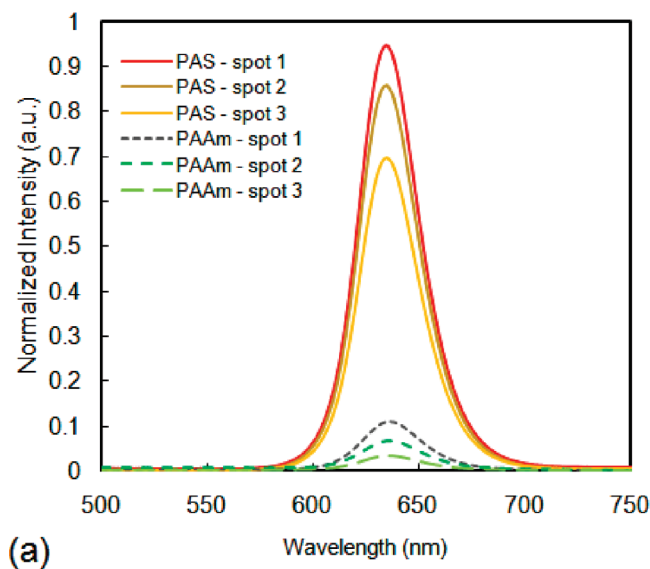


Figure 5. Amine functional group density comparison between iCVD PAS and PECVD PAAm: (a) photoluminescence (PL) results. Three different spots were measured for each sample. Fluorescence micrographs of (b) iCVD PAS and (c) PECVD PAAm. The images inserted in the top right of (b) and (c) represent a background when there are no quantum dots attached to the surface.

amine functional polymer enabled strong, hydrolytically stable bonding with simultaneous formation of reactive coatings within the microfluidic channels.

Si wafers, PC, glass, PET, PE, PA, and COC polymeric substrates were successfully bonded to PDMS, and the burst pressures were recorded in Table 2. There was no water leakage for the bonded devices under the pressure of 150 psi, when the glue used to seal the devices failed before the bond itself. This pressure exceeds the

Table 2. Burst Pressure of Microfluidic Devices Bonded with Various Kinds of Substrate Materials

material	burst pressure
PDMS–Si	> 150 psi
PDMS–PC	> 150 psi
PDMS–glass	> 150 psi
PDMS–PET	> 150 psi
PDMS–PA	> 150 psi
PDMS–COC	> 150 psi

requirements for many microfluidic applications.^{25–28} Furthermore, it is an addition reaction with no gaseous byproducts, which must diffuse away from the bonded area. In conventional bonding reactions, water must

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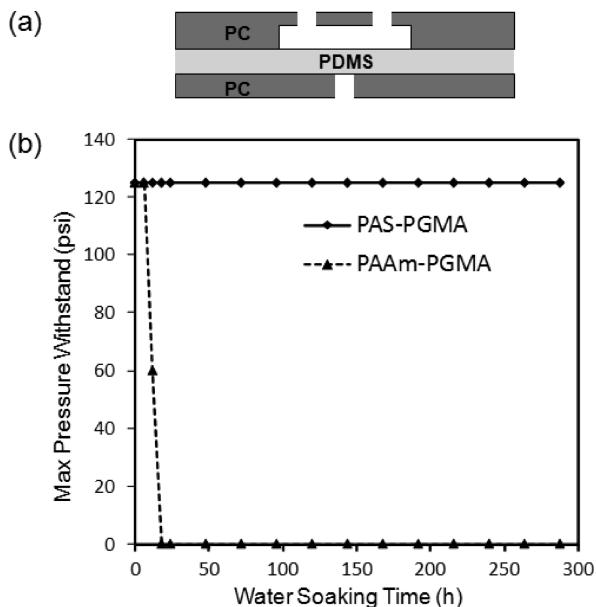


Figure 6. Hydrolytic resistance study: (a) schematic of a PC-PDMS-PC structure used in the blister test and (b) a plot of the channel maximum pressure versus water soaking time. The dotted line shows a marked bond strength decrease in devices utilizing PAAm-PGMA chemistry. The bond starts to degrade after 6 h and completely fails after 18 h. The solid line represents bond strength for devices utilizing PAS-PGMA chemistry. It remains almost unaffected even after 2 weeks.

outgas, possibly leading to leakage in the bonded substrates.

Hydrolytic Resistance. To test hydrolytic stability, the blister test structure was used as shown in Figure 6a. PC-PDMS-PC substrates were bonded together utilizing the bonding technique mentioned above. PGMA was deposited on both sides of PDMS, and PAS was deposited on the PC substrates. The well on the top PC substrate was used to store water, which would penetrate through the PDMS. In the blister test, argon flowed into the bottom PC through a needle, which was connected to polyester tubing by a universal barbed coupler (1/8", McMaster).

The highest channel pressure reported in Figure 6b (125 psi) is due to the maximum operation pressure of the barbed coupler used in the blister test. As shown in the figure, devices that utilized PAAm-PGMA chemistry showed bond strength degradation after 6 h in aqueous environment and it markedly decreased with the hydrolysis time. The device completely failed after 18 h soaking time with water, whereas those fabricated by iCVD films remained almost unaffected even after 2 weeks. Hydrolytic resistance relates to the hydrolytic stability of in-

dividual groups presented, steric hindrance and also the hydrophilicity of backbones.²⁹ The stable three-dimensional molecular structure of PAS provides a good steric barrier for water molecules to access, therefore the devices that utilized PAS-PGMA chemistry are much more hydrolytically stable. Hydrolytic stability is very important in microfluidic devices, especially for biological application. It usually takes days for cell culture growth. Even for fast-dividing mammalian cells, the length of the cycle is approximately 24 h. Bonding with long-term hydrolytic stability is critical in microfluidic device fabrication.

Conclusions

Amine functional thin films were successfully synthesized for the first time using iCVD with 4-AS as the monomer. FTIR and XPS results showed the similarity of the iCVD PAS films to the conventionally synthesized polymer. The iCVD method has advantages over the conventional PECVD process for producing conformal coatings within complex geometries and for retaining chemical functionality. The accessible amine sites on the PAS surface can serve as a scaffold for further functionalization or as sites capable of nanoadhesive bonding.

Si wafers, PC, glass, PET, PE, PA, and COC polymeric substrates were successfully bonded to PDMS, and the fabricated devices can withstand pressure > 150 psi. Sealing was achieved by bringing iCVD PGMA-coated flat substrate into contact with PAS-coated prepatterned surfaces and curing them at 50 °C for 24 h. The devices have conformal NH₂-functionalized coatings inside the microchannels, which prevent channel clogging and also enable the immobilization of biomolecules. Photoluminescence confirms that the reactive amine functional group density of iCVD PAS is approximately 1 order of magnitude higher than for films grown by PECVD, which results in possibly stronger bonding. Furthermore, the device is hydrolytically stable for more than 2 weeks, whereas devices that utilized PECVD PAAm-PGMA chemistry showed bond strength degradation after 6 h in the aqueous environment and complete device failure after 18 h.

Acknowledgment. The authors acknowledge financial support of the MIT Institute for Soldier Nanotechnologies (ISN) under Contract DAAD-19-02D-0002 with the U.S. Army Research Office. We thank Steven E. Kooi from ISN for his assistance with PL measurements and Jonathan Shu from the Cornell Center for Materials Research (CCMR) for his help with XPS measurements. We are also grateful for the PC substrates provided by Kevin Lee from MIT for the hydrolytic resistance test.

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